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DETERMINATION OF STRAW PARTICLE SIZE EFFECT ON THE WATER ABSORPTION OF STRAW-PLASTIC COMPOSITES

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ABSTRACT

The main aim of this paper is to present the research findings which come out from the experimental determination of the influence of input raw material properties and composition on the water absorption of straw-plastic composites (SPC). During the SPCs production, important raw material parameters such as straw sawdust particle size, straw/plastic concentration ratio or type of plastic matrix can be recognized. In this research study, the aim was to produce SPCs of an acceptable and competitive level of quality which is determined from the final mechanical properties of SPCs. Particle size of straw sawdust used for production of SPC has significant influence on mechanical properties of composites and also on other important properties (water absorption, hardness, frost resistance, etc.). The paper deals with the determination of the impact and the relationship between the input straw sawdust particles sizes, straw/plastic concentration ratio and water absorption of composites. By side intention of authors is to determine the possibilities of waste raw materials usage. The experimental research findings were obtained using a semi-operational injection molding press where the injection is provided by a working screw. As the input raw material, wheat straw, HDPE plastic matrix and recycled HDPE, represented by lids from PET bottles, was used. The effect of the input straw sawdust particle size on water absorption was determined according to a combination and default levels of straw/HDPE concentration ratio, using recycled HDPE instead of virgin HDPE and particle size of straw sawdust.

KEYWORDS: Straw sawdust, SPC, Straw-plastic composites, Particle size, Water Absorption, Recycling.

INTRODUCTION:

When producing the products based biomass-plastic composites, various fillers are added to improve the mechanical and physical properties of these composites. Nowadays, there is an increasing emphasis on environmental protection and there is more interest in replacing inorganic fillers with organic fillers, such as biomass for example wood, wheat straw, hay, corn stalks or rice husks. The development of renewable raw material composites has increased considerably in recent years due to their ecological and easy recyclability. Natural fibers are renewable, easily recyclable, carbon dioxide neutral and available in large quantities [1, 2]. The scope of use of biomass-plastic composites (BPCs) today is mainly in the automotive, engineering and electrical engineering industries. Also, various research studies [3, 4, 5] with material and technological variables effect on the production are dealing with. BPCs are produced by thoroughly mixing ground biomass particles and heated thermoplastic resin [6, 7, 8]. The most common method of production is to extrude the material into the desired shape using injection molding or extruding, however, we can see also production of composites using additive manufacturing resp. 3D printing. BPCs may be produced from various virgin thermoplastics but polyethylene based BPCs are by far the most common [6]. The usual composition of BPCs based virgin material is 60 - 65% of high-density polyethylene (HDPE) [6, 9], 30 % of biomass particles without defined granulometry, but the particle sizes up to 2 mm and the additives according to the final application, which helps tailor the end product to the target area of application [5].

The main challenges in this area is to gain the research findings about waste recovery possibility that can show the possibility and application of straw-plastics composites (SPCs) based waste raw materials. Obtained research findings can be very helpful at SPCs production and shown the possibility of using also waste raw materials for SPC products and using of such a composites for rapid prototyping which is very interesting issue and recovery possibility for nowadays. Therefore the main activities are focused on determination of the material variables effect on mechanical properties of SPCs based waste raw materials. According to our previous basic research, analyses of available research findings [2, 3, 4, 6, 7, 10] and knowledge an important input variables such as raw material´s parameters, especially (type of raw material and straw sawdust particle size) can be recognized during the production of SPCs [1, 2]. Their impact can be seen through the quality indicators; especially mentioned parameters significantly influence the mechanical properties of SPCs (ultimate strength, maximal force, elongation, impact strength, toughness, modulus of elasticity, water absorption, hardness, etc.) [4, 6, 10]. Most important is the role of biomass particle size, in this case the straw sawdust.

The general purpose of this paper is to present the research findings regarding the effect of particle size and percentage amount of straw sawdust in composites on the water absorption of straw-plastic composites. Authors would like to present this effect also in case of SPCs based virgin thermoplastic and also in case of SPCs based waste raw materials. Such of results are very important and interesting from the production possibilities and applications of SPCs based waste raw materials point of view. Obtained future research findings can be very helpful at SPCs production using 3D printers and shown the possibility of using also waste raw materials for SPC products, and thus increase the environmental responsibility with the environment protection.

MATERIALS AND METHODS:

The main aim of our experiment is to determine the effect of raw material properties (particle size of straw sawdust) on the water absorption of straw-plastic composites. For purposes of determination this effect, the basic raw materials had to be chosen and prepared. HDPE (high-density polyethylene named TIPELIN 1108J from Slovak company Slovnaft a.s. Bratislava, with the melt index 8.0 g / 10 min), HDPE rec. (recycled high-density polyethylene originating from lids of PET bottles) were used as plastic matrices. Wheat straw sawdust originating from Western Slovakia was obtained from agricultural company. This kind of agricultural crop is a typical crop in Slovakia and are widely and usually cultivated in our country. Samples of wheat straw in the untreated form were obtained from an agricultural company. For processing the straw to the form of straw sawdust the hammer mill STOZA ŠV5 equipped with screen 8.0 mm and 4.0 mm in diameter was used. On Figure 1 can be seen the achieved samples of straw sawdust after shredding. Shredding on two level was used, for obtaining proper amount of samples with suitable level of fineness. Initially, Retsch Vibrating Sieve Equipment AS 200, according to the EN ISO 17827-1 [11], for analyzing of the particle size distribution (Figure 2) was used. Figure 2 shows the raw material particle size distribution.

Fig. 1: Shredding of straw to the samples of straw sawdust – with particles up to 0.5 mm (left), with particles up to 1.0 mm (right)

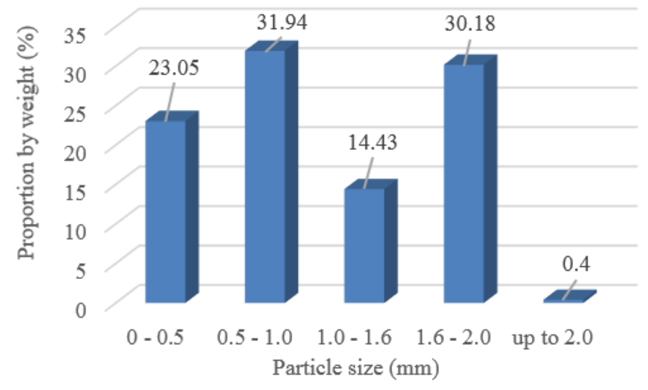

Fig. 2: Raw material particle size distribution of the samples studied

In our case, determination of the mutual interaction between water absorption of SPC´s samples, type of the plastic matrix used in SPCs, straw/plastic concentration ratio and particle size of straw sawdust used in SPCs were chosen [12]. Experimental research was done according to the designed experimental plan where the full factorial experiment was used [13]. Experimental research consisted of 3 influencing parameters, the specific type of polymer matrix - on 2 levels, particle size - on 2 levels and concentration ratio of plastic/straw where the 90:10, 80:20, 70:30 ratios were used (see Table. 1).

Tab. 1: Input controllable variables of the experiment [12]

	Variables		
Levels	Straw/Plastic ratio (%)	Particle size (mm)	Polymer matrix type (-)
1	0 / 100	0 - 0.5	HDPE
2	10 / 90	0.5 - 1.0	HDPE rec.
3	20 / 80	-	-
4	30 / 70	-	-

Because the experimental research with raw waste materials was dealt and according to given experimental plan straw for the experiment had been treated. For obtaining the given straw particle sizes the disintegration and separation processes were used. According to our knowledge as a particle size only particles 0-0.5 mm and 0.5-1.0 mm were chosen [12, 14]. Bigger particles are not usually used during the production of SPCs. For this experiment a wheat straw sawdust with up to 0.5 mm and up to 1.0 mm particle size was used (Figure 1), with properties shown on Figure 2. The moisture content of chosen straw before mixing, extrusion and injection were measured with the aid of a Kern MRS 120-3 balance.

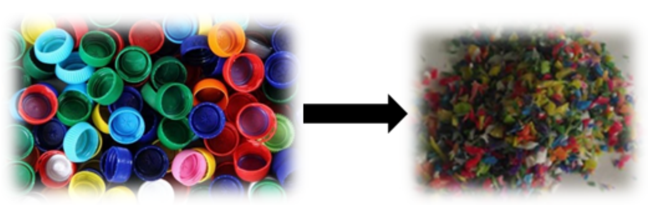

Fig. 3: The disintegration of PET bottle lids

This measurement consisted of heating the raw feedstock (gravimetric method of moisture content measuring) [15] at 105 ± 2°C until a constant weight was achieved. The moisture content of straw sawdust on the level of 1.5 % was prepared. For disintegration of PET bottle lids (Figure 3) cutting mill Retsch SM 300 was used. A set number of samples for testing will be produced according to the designed experimental plan shown in Table 2. The used injection mold is produced according to ISO 527-2 / 1A / 10. It is used to injection of normalized tensile test specimens. On the Figure 4 can be seen the shapes of normalized testing specimen after injection. For each set according to the experimental plan at least 12 specimens were produced and during the injection the operating parameters of injection press were recorded. The operating parameters of injection process according to the requirements for proper filling the form have been adjusted for production of specimens with expected quality and to avoid the formation of bubbles inside and to collapsing the specimen sides.

Tab. 2: Designed composition of experimental research [12]

Number of setting	Polymer matrix type (-)	Plastic/straw ratio (%)	Particle size (mm)
1.	HDPE rec.	90/10	0 - 0.5
2.	HDPE rec.	80/20	0 - 0.5
3.	HDPE rec.	70/30	0 - 0.5
4.	HDPE rec.	90/10	0.5 - 1.0
5.	HDPE rec.	80/20	0.5 - 1.0
6.	HDPE rec.	70/30	0.5 - 1.0
7.	HDPE	90/10	0 - 0.5
8.	HDPE	80/20	0 - 0.5
9.	HDPE	70/30	0 - 0.5
10.	HDPE	90/10	0.5 - 1.0
11.	HDPE	80/20	0.5 - 1.0
12.	HDPE	70/30	0.5 - 1.0
13.	HDPE rec.	100/0	N/A
14.	HDPE	100/0	N/A

Fig. 4: Testing specimen for tensile test after injection

The experimental samples production process can be seen in Figure 5. Given straw/plastic ratios had to be prepared by mixing with using a usual electric mixer, weight by using MR 120 balance was controlled. Composites granules for injection by twin-screw extruder LTE26 and final specimens by Mitsubishi 180 MEt III injection moulding machine were produced. Specimens dimensions related to the Standard STN EN ISO 527-3 were produced [16].

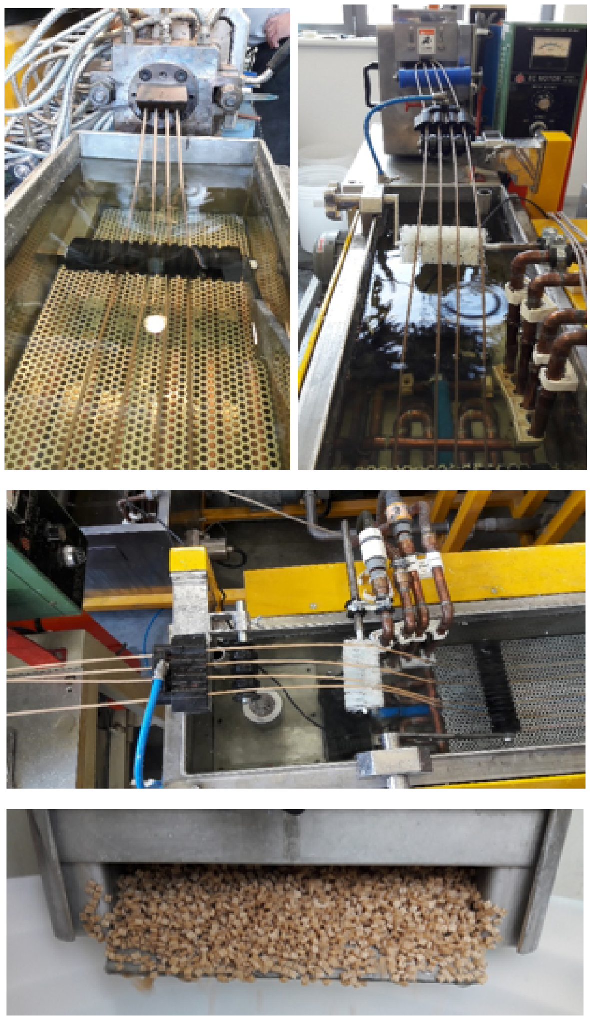

Fig. 5: Extrusion and production of composites strings by twin-screw extruder and composites granules by cylindrical shredder

As was mentioned above, for each setting according to the experimental plan a specific number of specimens (Figure 4) were produced. Specimen seen on the Figure 4 is usually used for tensile test, in which a sample is subjected to a controlled tension until failure. In our case, the effect of particle size on water absorption and the effect of particle size on SPCs density will be determined using specimens for tensile test. Straw-plastic composites can absorb different amounts of water and thus its presence can significantly affect material properties such as electrical insulation resistance, mechanical properties, dielectric loss, dimensions or density. The absorbency of straw-plastic composites is influenced by the final composition of the material [17, 18]. Therefore the following determination methodology of water absorption was used. The SPC specimens were immersed in distilled water and thus exposed to high humidity. Percentage weight gain during immersion was measured by Kern MR 120 digital balance and was calculated by following equation (1) [17, 18]:

$$water\ absorption = \frac{specimen\ weight\ in\ time - initial\ weigth\ of\ specimen}{initial\ weigth\ of\ specimen} \cdot 100\ (\%)$$

For the determination of SPCs density the digital caliper Mitutoyo 500-196-20 when the length, width and thickness of specimen was measured. These values for the calculation of specimen's volume was used and within the weight of specimens the densities were calculated.

RESULTS AND DISCUSSION:

According to the experimental plan (Table 2), testing specimens were produced. Determination of density with specimens shown in Figure 4 was provided. On the following Figure 6 can be seen the effect of straw particle size in combination with plastic/straw ratio on the composites density. This figure shown this effect at composites produced from the virgin HDPE matrix and also from the recycled HDPE. We can see that in all settings, composites based recycled HDPE has higher density value. This is caused by using of unspecified sample of lids from PET bottles. When we look closer on the effect of straw particle size on the density, we can see that the composites containing smaller particles (0 – 0.5 mm) have higher densities comparing the composites containing higher particles (0.5 – 1.0 mm). This is a logical output because smaller particles have higher compressibility and during the injection process is possible produce composites with higher the density.

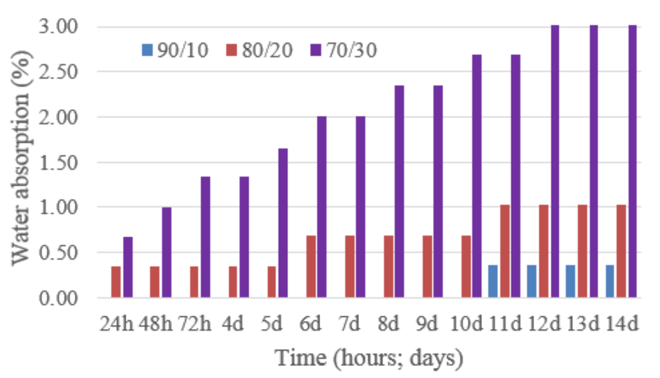

Fig. 7: Dependence of water absorption on composite´s immersion time (composites based recycled HDPE, particle size 0 – 0.5 mm)

On Figure 7 and Figure 8, the dependence of water absorption on composite´s immersion time is displayed. Here the results intended to a composites based recycled HDPE are presented. Figure 7 the dependence of water absorption on composite´s immersion time is displayed, where the composites based recycled HDPE containing particle size 0 – 0.5 mm are compared. The highest water absorption at composites produced from 70/30 plastic/straw ratio was determined. We can see that with higher percentage of straw sawdust in composites also increases the water absorption within the immersion time. The step changes can be seen, where the composites with different straw sawdust percentage absorbed water stepwise, e.g. absorption value in % after several days was changed.

Figure 8, the dependence of water absorption on composite´s immersion time is displayed, where the composites based recycled HDPE with particle size 0.5 – 1.0 mm are compared. Here the situation is a little bit different. In general, the water absorption with lower percentage values were determined, but the composites absorbed the water faster than composites from 0 – 0.5 mm particle size. Bigger straw particles influences the bindings creation during composites production and thus also the water absorption.

On Figures 9 and 10, the dependence of water absorption on composite´s immersion time is also displayed. But here the composites based virgin HDPE are presented.

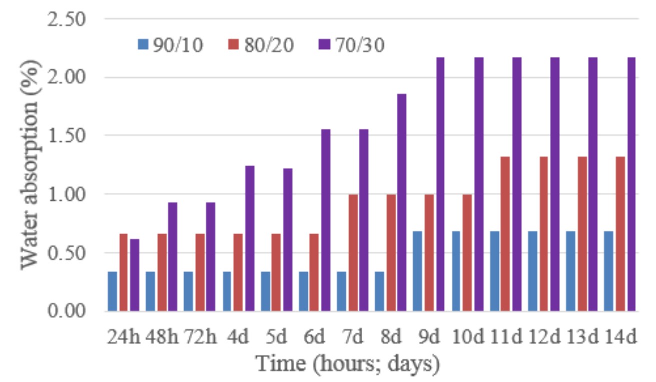

Fig. 8: Dependence of water absorption on composite´s immersion time (composites based recycled HDPE, particle size 0.5 – 1.0 mm)

Figures 9 and 10 displayed separately the composites with straw particle size 0 – 0.5 mm and composites with straw particle size 0.5 – 1.0 mm within the plastic/straw ratio. The fact with the highest water absorption at composites produced from straw particles 0.5 – 1.0 mm at 70/30 plastic/straw ratio was proven also here. We can see that with increasing percentage of straw sawdust also increases the water absorption of composites.

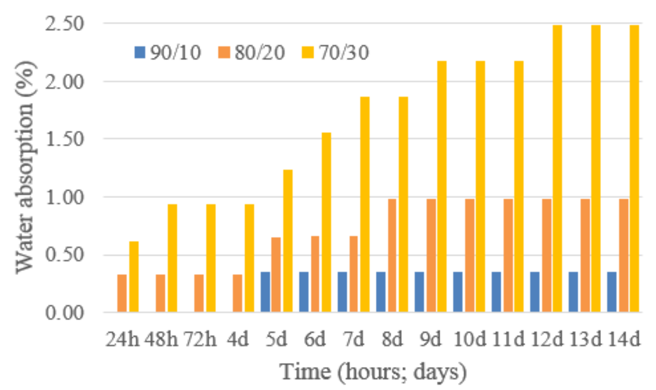

Fig. 9: Dependence of water absorption on composite´s immersion time (composites based virgin HDPE, particle size 0 – 0.5 mm)

The general trend in straw particle´s effect on water absorption is the same. We can see that with higher percentage of straw sawdust in composites also increases the water absorption within the immersion time. The same effect has the particle size on absorption speed. With increasing the particle size also increases the water absorption speed. According to the general comparison, the virgin HDPE seems less appropriate than recycled HDPE from water absorption point of view. On the other hand, this is a positive research finding from the environmental point of view. Whereas composites are mostly used for outdoor applications, water absorption is a very important behavior, even if we can reach better results with recycled wastes.

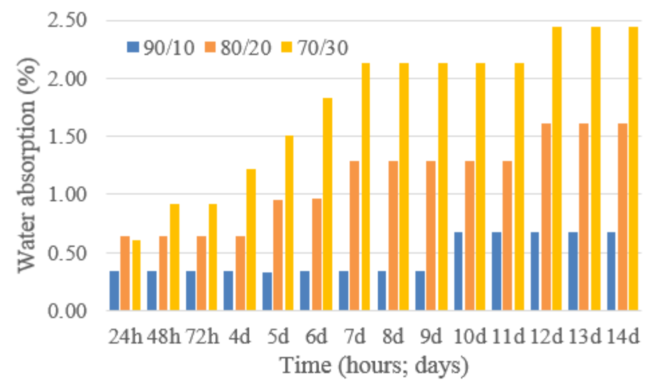

Fig. 10: Dependence of water absorption on composite´s immersion time (composites based virgin HDPE, particle size 0.5 – 1.0 mm)

When comparing the water absorption in composites based recycled and virgin HDPE (Figure 11 and 12), the results are changes on the base of particle size of straw sawdust in composites. Composites based recycled HDPE (ratio 70/30) with particle size 0 - 0.5 mm have higher water absorption and also absorbed

water faster. This comes out from the differences of plastic matrixes used in both cases.

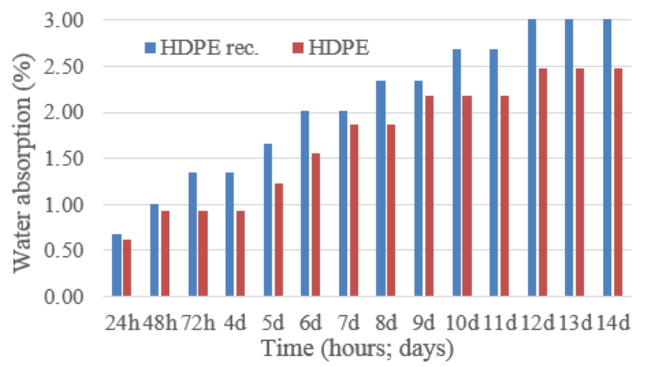

Fig. 11: Dependence of water absorption on composite´s immersion time (composites with ratio 70/30 with particle size 0 – 0.5 mm)

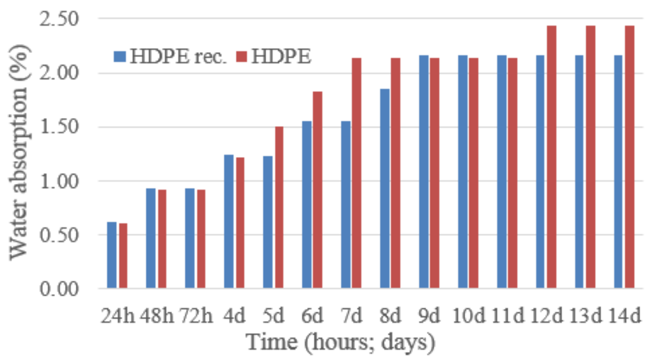

Fig. 12: Dependence of water absorption on composite´s immersion time (composites with ratio 70/30 with particle size 0.5 – 1.0 mm)

By the composites with particle size 0.5 – 1.0 mm is situation a little bit different (Figure 12). Composites based virgin HDPE (ratio 70/30) with particle size 0.5 - 1.0 mm have higher water absorption and also absorbed water faster from 5th day of immersion. We can see that first four days of immersion, the composites absorption was on the same level. After the composites based virgin HDPE absorbed more water that composites based recycled HDPE. This comes out from the straw particles behavior.

CONCLUSIONS:

Research of plastic and straw raw waste materials recovery was investigated in this research. Presented results of preliminary phase relates to the effect of straw sawdust particle size and properties on water absorption of the SPCs., effect of particle size effect plastic matrix used in composites and effect of straw/plastic concentration ratio.

The main conclusions that can be withdrawn from this study are as follows:

- HDPE recycled originating from PET bottle lids can be used for composites production,
- Composites based HDPE recycled had higher water absorption than composites based virgin HDPE,
- Composites based virgin HDPE had faster water absorption than composites based recycled HDPE,
- Straw/plastic ratio affects the water absorption, with increasing of this ratio, e.g. with increasing amount of straw sawdust in composites also increases the water absorption,
- Straw sawdust particle size affects the water absorption, it depends also on Straw/plastic ratio.

Additional phase of this experimental research will concern to research of plastic and straw raw waste materials recovery with using a rapid prototyping technology. Research of basic material composition suitable for 3D printing and development of SPC´s composition based on waste materials which can be used for 3D printing is very ambitious and interesting issue.

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